Source to mouth sediment budget of the Rhine River – Contributions to river basin management

Gudrun Hillebrand, Thomas Hoffmann, Stefan Vollmer, Roy M. Frings

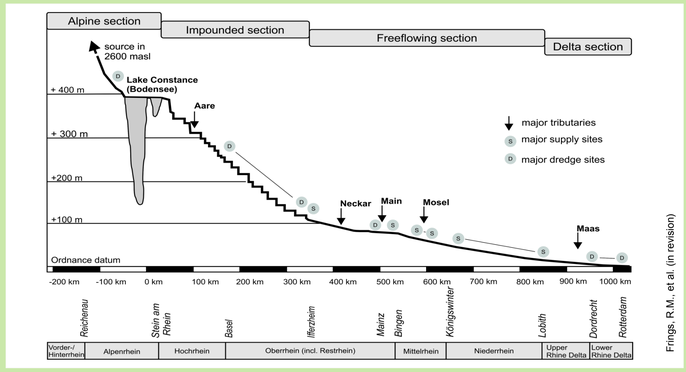
Bundesanstalt für Gewässerkunde

Aims

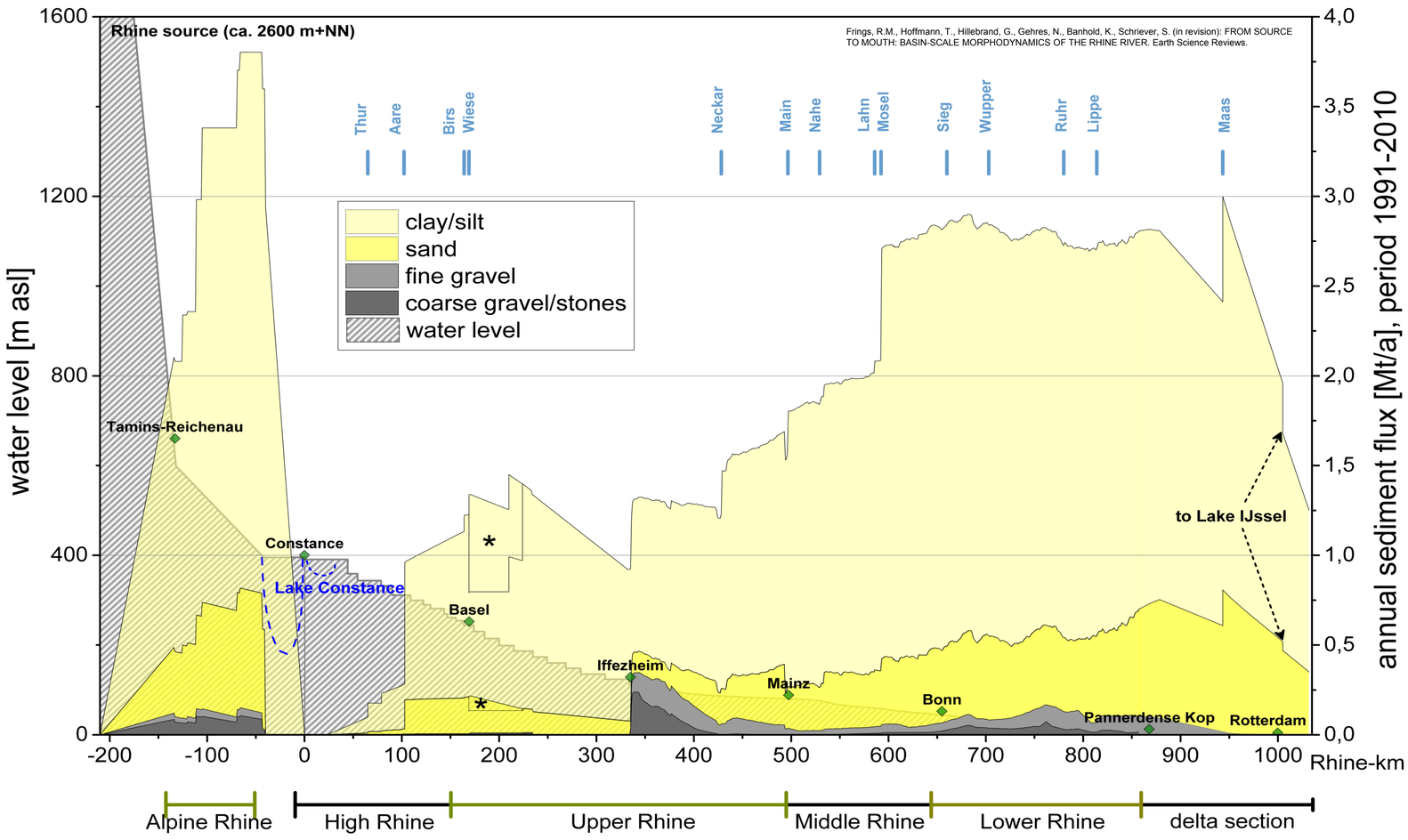
- Quantify the downstream fluxes of clay, silt, sand, gravel and cobbles
- Identify the sources and sinks of these sediments

Scope

- Full 1,232.7 km long river from its source in the Swiss Alps towards its mouth in the North Sea
- Subdivision into morphologically different sections
- Period 1991 to 2010
- Evaluate the behavior of the clay, silt, sand, gravel and cobble fractions separately



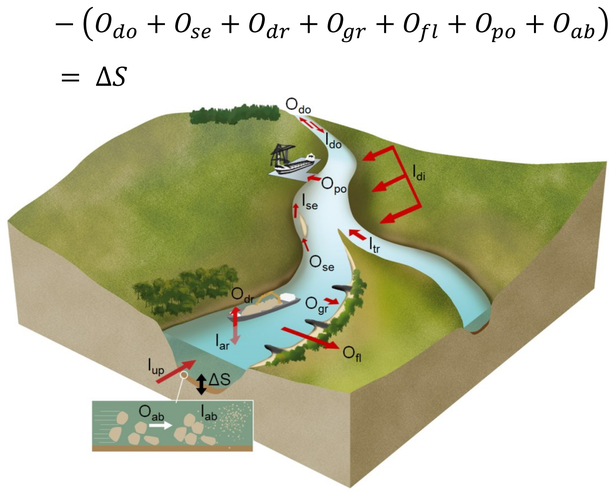
Result 1: Mean annual sediment fluxes



Method

- Sediment budget analysis:
  mass balance between the sediment input (I), output (O) and storage (ΔS) of an area of interest in a period of time: **I – O = ΔS**

$$(I_{up}+I_{tr}+I_{se}+I_{di}+I_{ar}+I_{ab}+I_{do}) - (O_{do}+O_{se}+O_{dr}+O_{gr}+O_{fl}+O_{po}+O_{ab}) = \Delta S$$



Data base

Morphological studies about the Rhine, carried out in the past decades, and existing data were re-analyzed.

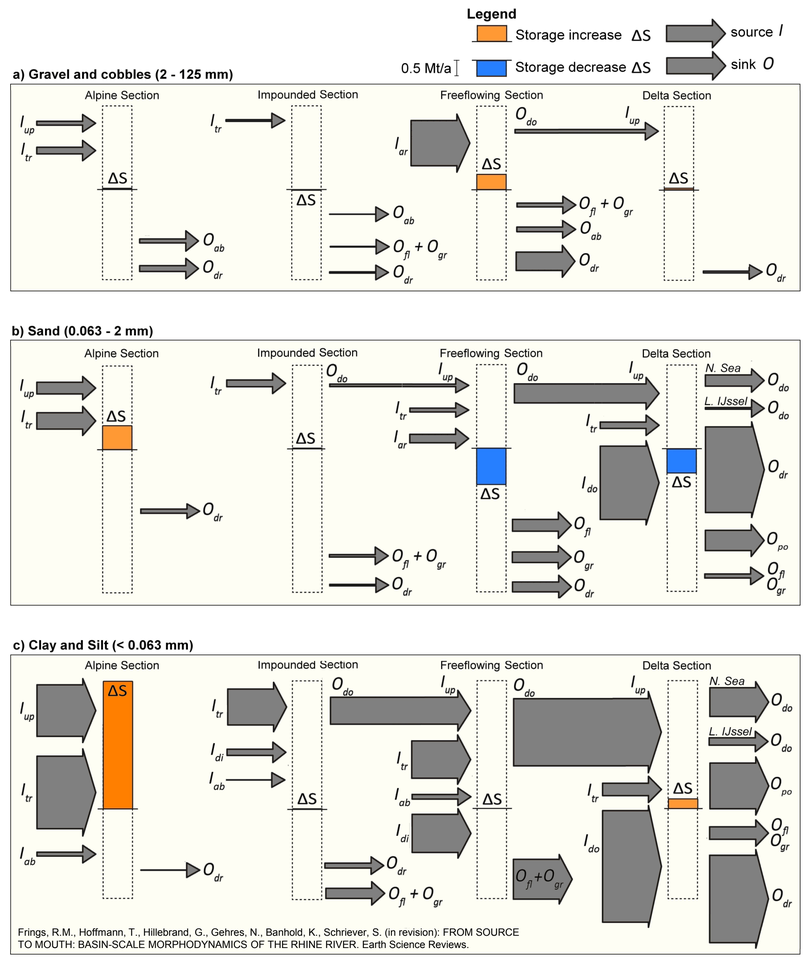
Existing/literature data used in the study:

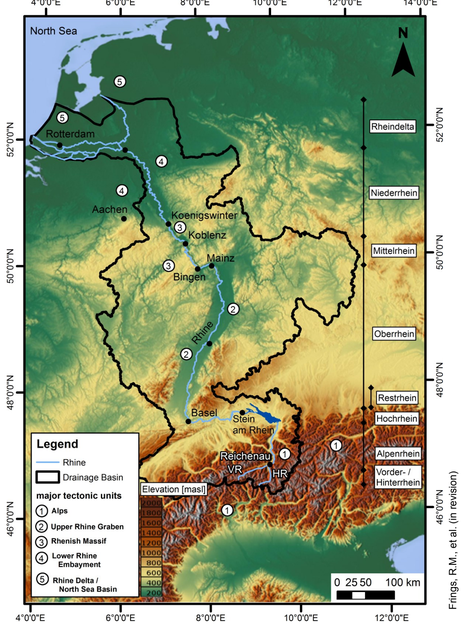
- Bed load (gravel, sand) — *≈ 1400 measurements*
- Suspended load (sand, clay/silt) — *≈ 500 cross-sectional + 50000 point measurements*
- Amount and composition of artificial inputs — *≈ 3000 measures*
- Dredging volumes — *≈ 3000 measures*
- Bed elevation (echo-soundings)
- Bed grain size composition — *≈ 10000 sieve curves*
- Abrasion rates
- Sedimentation rates on floodplains

Additional measurements:

- Sedimentation rates on floodplains
- Grain size composition of suspended loads
- Sand loss in bed load measurements

Result 2: Sediment budgets





Conclusions

- On a basin-scale, nourishment represents the biggest source of gravel and cobbles, and tributaries the biggest fluvial source of clay, silt and sand. In the lower Rhine delta, additionally large amounts of clay, silt and sand are supplied by the sea.
- Dredging represents a main sediment sink for all size fractions. For silt and clay, also floodplain deposition and deposition in ports represent major sinks. Sediment output to the North Sea is limited.
- Today's sediment fluxes in the Rhine are strongly influenced by river training works from the past, as well as by present-day dredging and nourishment operations. This notwithstanding, natural factors determine the location of the main sedimentation areas.
- The behaviour of the clay/silt, sand and gravel/cobble fractions strongly differ from each other. Particularly, in many reaches gravel is deposited, whereas sand is being eroded simultaneously.
- The budget analysis shows that sediment dynamics in rivers are much higher than is suggested by echo-soundings or transport measurements, and it also shows that sand plays a dominant role in the morphodynamics of the Rhine, not only in the sand-bed reaches, but also in the gravel-bed reaches of the river.

This study was carried out under the banner of the International Commission for the Hydrology of the Rhine Basin (CHR) and financed jointly by the Federal Institute of Hydrology (BfG) and the Institute of Hydraulic Engineering and Water Resources Management of RWTH Aachen University (IWW), with contributions of Rijkswaterstaat, WSA Duisburg-Rhein and the CHR.

Federal Institute of Hydrology

Am Mainzer Tor 1
56068 Koblenz
Germany

Department M3 - Groundwater, Geology, River Morphology

Dr.-Ing. Gudrun Hillebrand
hillebrand@bafg.de

Project partner:
RWTH Aachen University
Institute for Hydraulic Engineering and Water Resources Management

Dr. Roy M. Frings
frings@iww.rwth-aachen.de

06/2017

10th International SedNet Conference "Sediments on the move" 14-17 June 2017 at the Palazzo San Giorgio, Genoa, Italy